other from the spring-like afternoons of winter to the desert heat of the summer afternoons.

A criticism of all climographs should be emphasized here, namely, that they can not show graphically the very important item of wind velocity as a determinant of human sensation in connection with temperature and relative humidity. The makeshift here adopted of placing alongisde of the month or hour points the average

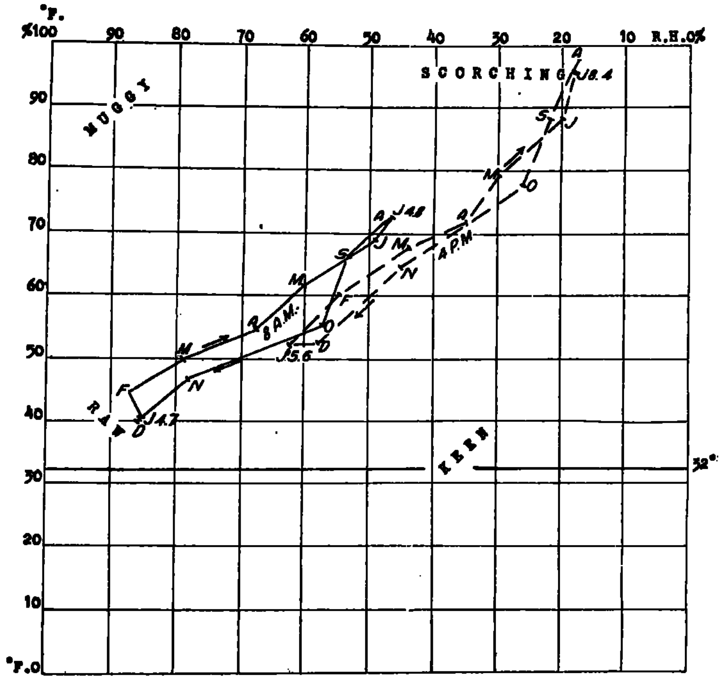

FIG. 4.—Monthly averages of air temperature and relative humidity at 8 a. m. and 4 p. m., Fresno, Calif. 8 a. m.=solid line, 4 p. m.=broken line. Mean wind velocities for January and July near initial letters of those months.

wind velocity is obviously unsatisfactory, but still a help to the fuller interpretation of the graphs.

Finally, figure 5 is presented to show the versatility of the climograph in illustrating the effects of nonperiodic weather changes. The example is that of an interruption of the smooth summer coolness at Berkeley, Calif., on the coast, by the passage of the center of a pronounced high pressure north of the station. Daily maxima of temperature and minima of relative humidity indicate the progress of the change from the 19th of the month through the 30th, and letters show the prevailing wind direction for the corresponding days.

From positions in the "moderate" area of the figure, the succession of points suddenly trends out into the "scorching" area, showing at a glance what would otherwise need two curves and considerable description to make clear.

The climograph can be used in visualizing the effect of other cyclonic weather changes, such, for instance, as

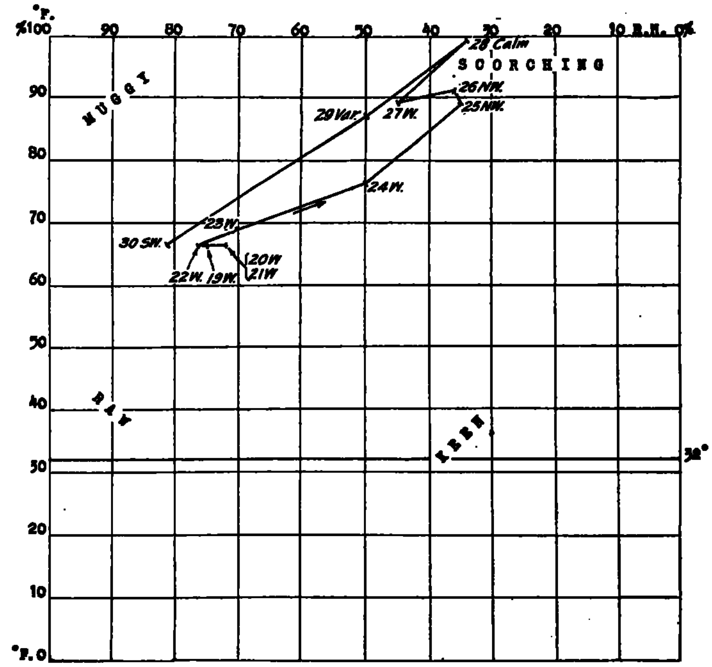

FIG. 5.—Effect of a hot wave on daily maxima of air temperature and minima of relative humidity at Berkeley, Calif., Sept. 19 to 30, inclusive, 1917. Figures=dates, letters=prevailing wind direction on the given date.

occur at the passage of the wind-shift line. With it one's conception of the effects of thunderstorms, sea breezes, Texas northers, and many more of the important characteristics of local climate and weather can be made more vivid. With it the climatologist can illuminate somewhat more brightly the endless columns of data which too often are dark and uninteresting to the "average man." And, like the curve, the climograph can be used with moderation.

THE KATATHERMOMETER: AN INSTRUMENT TO MEASURE BODILY COMFORT.

By ROBERT A. JACOB.

[U. S. Naval Proving Ground, Dahlgren, Va., June 30, 1920.]

It has long been known that dry-bulb readings do not furnish a definite index of bodily comfort. The human body is a dynamic organism, maintaining, under normal health, a nearly constant temperature in the close neighborhood of 98.6° F. This standard condition is controlled physiologically by the heat gained in the internal combustion of food and by regulation of the amount of heat lost from the skin and respiratory membranes. Since the air temperature is generally far below 98.6° F., it is seen that the body may be thought of as a mass of hot matter constantly losing heat, which loss is perpetually being made good by physiological changes which very nearly maintain the uniform thermal standard referred to above. When the rate of loss remains greater than the rate of gain for any considerable period we say we are cold; when the rate of gain becomes and remains greater than the rate of loss we say we are hot.

In either case we are uncomfortable and a regulation of one or both is necessary to reinstate a condition of comfort. To all intents the rate of heat gain is beyond our control and so our efforts to remain comfortable have to do with a regulation of the rate of heat loss from the body. Obviously we are interested in this discussion in the measurement of the effect of the atmospheric condition on the body.

The methods we have at present for measuring the departure of our atmospheric environment from that standard which produces the greatest comfort are wholly inadequate. Measurements of dry temperature and relative humidity by means of the wet-bulb thermometer do not give a true idea of the condition. The dry thermometer is a static instrument and averages the influences of the environment, while the body, as has been said above, is a dynamic organism maintaining by its own physiological activities a constant temperature. As for instruments to measure relative humidity, it is sufficient to say that these instruments do not indicate the conditions they are designed to measure as accurately as they should. Together with temperature and relative humidity, bodily comfort is also affected by air movement, or, reducing the whole matter, we may say that the loss of heat from the body to the atmosphere in general and air movements which remove the saturated and heated air and supply cooler and drier air are the conditions which affect bodily comfort.

As early as 1826, Dr. Heberden (1) suggested that observation of the rate of fall of a thermometer, previously heated, would furnish data for the computation of bodily comfort. He heated a thermometer to 100° F. and noted the number of degrees which it fell in 10 minutes as a measure of "sensible cold."

In 1875 Prof. J. W. Osborne introduced an apparatus which involved a wet cylinder of paper containing warm water as a quantitative measure. Mr. A. Piche, brought forward a similar instrument which he called a *deperditometer* (2). He measured the amount of gas necessary to maintain the water at body heat, the gas being regulated automatically. Prof. J. R. Milne's "constant temperature" *psuchrainometer* (3) was introduced in 1911 and was soon followed by his "constant energy" type of the same instrument. Electrical heating and measurements were used. He deduced an empirical formula giving the rate of cooling as a function of temperature and wind velocity.

In 1911, Dr. F. Frankenhäuser (4) introduced an instrument called the *homœotherm* for measuring the cooling effect of temperature, moisture, wind, solar radiation, etc. It consisted of a small copper cylinder filled with water in which was plunged a thermometer. It was so designed that a fall of one degree centigrade corresponded to the loss of one gram calorie. Various thicknesses of different textiles were wrapped around the cylinder to approximate more closely the environment of the body. It was noted that an increase in wind velocity had a more marked effect than a sharp fall in temperature.

Prof. Leonard Hill introduced two instruments; one, the *caleometer* devised in collaboration with Prof. O. W. Griffith, consists of a small electrical furnace automatically kept at body temperature and working on much the same principle as instruments of the same class already mentioned. The other invention is the *katathermometer* (5) and was first described by the inventor in 1913.

The katathermometer outfit consists of two specially constructed thermometers with large bulbs and stems graduated from 86° to 110° F., one to be used as a dry and the other as a wet bulb thermometer. The bulbs are heated by means of hot water to a temperature of about 110° and place in clips which hold them in a horizontal position, after drying the one and removing the excess moisture from the other. The time taken for each thermometer to fall from 100° to 90° F. is observed by means of a stop watch and these readings serve as values to be transformed into an index representing the cooling effect of the air immediately surrounding the body.

On an ideal spring day the wet has been found to take 45 seconds and the dry 2 minutes 20 seconds. Under any conditions the maximum time for the wet sould be 1 minute and the dry 3 minutes. Factors have been determined for each thermometer so that the rate of cooling can be expressed in milli-calories per square centimeter per second. The rate of fall of both thermometers will be affected by air movement and radiant heat as well as by air temperature, and the wet bulb will also be affected by the humidity. An extended series of experiments was made by Prof. C.-E. A. Winslow (6) of the Yale Medical School, using this apparatus.

Three series of experiments were made under varying conditions, the results in each case being compared with the vote of from three to twenty observers, who expressed their opinion on an arbitrary scale as follows: 1, cold; 2, cool; 3, ideal; 4, warm; 5, hot. The deductions drawn show that although the katathermometer appears to be unduly influenced by air movement, "it seems clear that this instrument is of great value in measuring the actual influence of air conditions upon the body and is greatly superior to the ordinary thermometer for this purpose."

Messrs. Hill, Griffith, and Flack have published an important contribution (7) in which the readings are expressed in the fundamental units of milli-calories per square centimeter.

Empirical formulas have been deduced for the measurement of heat loss as follows:

For the dry kata— $H=(0.27+0.49\sqrt{V})(T-t)$.

For the wet kata— $H'=(0.27+0.49\sqrt{V})(T-t)+(0.085+0.102V^{0.3})(F-f)^{4/3}$

where H, H' are the heat losses from the dry and wet katas, respectively, in milli-calories per square centimeter per second, V is the wind velocity in m. p. s., T is the katatemperature (36.5° C.), t is the air temperature (° C.), F the saturation vapor pressure at 36.5° C. (45.4 mm.), and f is the vapor pressure of the air.

Mr. C. W. B. Normand (8) has recently published an extensive article in which he discusses what he calls the "upper climatic limit." In this discussion is a good account of the katathermometer with several graphs. He finds that for ordinary conditions the wet kata is very suitable but, under those conditions of temperature, air movement and humidity which tend to make life cease, he finds that a large-bulbed wet thermometer is more desirable.

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THE SCIENCE OF VENTILATION AND OPEN-AIR TREATMENT.

By Dr. LEONARD HILL.[1]

The British Medical Research Council has just issued, under the title of "The Science of Ventilation and Open Air Treatment," a very commendable study upon the important relations between atmospheric conditions, health and comfort. The work of Dr. Leonard Hill on

[1] The Italian Government has conferred upon Dr. Leonard Hill, F. R. S., the Italian silver medal "Ai Benemeriti della Salute Publica." (Science, New York, Oct. 15, 1920, p. 358.)